FINAL REPORT

Live Site Demonstrations: Former Pole Mountain Target and Maneuver Area, Laramie, WY

MetalMapper Data Analysis for Pole Mountain Target and Maneuver Area

ESTCP Project MR-201157

March 2012

John Baptiste
Parsons

REPORT DOCUMENTATION PAGE			*Form Approved* *OMB No. 0704-0188*

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
08-03-2012	Final	May 2011 - March 2012

4. TITLE AND SUBTITLE Final Report Live Site Demonstrations Former Pole Mountain Target and Maneuver Area Laramie, WY	**5a. CONTRACT NUMBER** WH912HQ-11-C-0044 **5b. GRANT NUMBER** **5c. PROGRAM ELEMENT NUMBER**
6. AUTHOR(S) Baptiste, John E.	**5d. PROJECT NUMBER** MR-201157 **5e. TASK NUMBER** **5f. WORK UNIT NUMBER**
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Parsons 1700 Broadway Denver, CO 80290	**8. PERFORMING ORGANIZATION REPORT NUMBER**
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) Environmental Security Technology Certification Program Program Office 901 Stuart Sreet Suite 303 Arlington, VA 22203	**10. SPONSOR/MONITOR'S ACRONYM(S)** ESTCP **11. SPONSOR/MONITOR'S REPORT NUMBER(S)**

12. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

This project involved the processing and analysis of MetalMapper data collected at the Pole Mountain Target and Maneuver Area. 2,370 data files were inverted and analyzed using the UX-Analyze add-on to Geosoft's Oasis Montaj software package. Once analysis was complete, ranked dig lists were submitted for scoring by the Institute for Defense Analyses. Dig list scoring was based on the number of targets of interest correctly identified as items that should be dug and the number of non-TOI or clutter items that were correctly classified as items that did not need to be intrusively investigated. Two dig lists submitted by Parsons were scored against ground truth data generated during the intrusive investigation performed at the site following MetalMapper data collection. Both dig lists correctly identified all of the TOI on site as TOI, so the only distinction between the two was the amount of clutter correctly classified as clutter. The better performing of the lists reduced the amount of clutter that needed to be intrusively investigated by approximately 79 percent, and the other reduced the clutter digs by approximately 73 percent.

15. SUBJECT TERMS

MetalMapper, UX-Analyze, UXO, Pole Mountain Target and Maneuver Area, discrimination, classification

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			John Baptiste
U	U	U	UU	41	19b. TELEPHONE NUMBER *(Include area code)* (303) 579-0909

Final Report

Table of Contents

Figures

Tables

Acronyms

cm	centimeter
DAQ	data acquisition computer
DoD	Department of Defense
EMI	electromagnetic induction
ESTCP	Environmental Security Technology Certification Program
GPS	global positioning system
Hz	hertz
ID	identification
IDA	Institute for Defense Analyses
in.	inch
ISO	industry standard object
LBNL	Lawrence Berkeley National Laboratory
m	meter
MEC	munitions and explosives of concern
mm	millimeter
PMTMA	Pole Mountain Target and Maneuver Area
ROC	receiver operating characteristic
Sky	Sky Research, Inc.
SERDP	Strategic Environmental Research and Development Program
SLO	Camp San Luis Obispo
TOI	target of interest
UXO	unexploded ordnance

EXECUTIVE SUMMARY

This report describes in detail the procedures, methods, and resources Parsons used to complete the demonstration project at the former Pole Mountain Target and Maneuver Area (PMTMA) for Environmental Security Technology Certification Program (ESTCP) Project MR-201157 (Demonstration of MetalMapper Static Data Acquisition and Data Analysis). The 2011 ESTCP Unexploded Ordnance Classification Study, Pole Mountain Target and Maneuver Area, Wyoming was conducted with two primary objectives:

- Test and validate detection and discrimination capabilities of currently available and emerging advanced electromagnetic induction sensors developed specifically for discrimination on real sites under operational conditions.
- Investigate in cooperation with regulators and program managers how classification technologies can be implemented in munitions and explosives of concern (MEC) cleanup operations.

Parsons' responsibilities on this project included only the processing and analysis of MetalMapper data collected at the PMTMA site by Sky Research, Inc (Sky). The MetalMapper is an advanced electromagnetic induction system developed by Geometrics, Inc., with support from the ESTCP. It has three mutually orthogonal transmit loops in the Z, Y, and X directions and contains seven tri-axial receiver antennas inside the Z (bottom) loop, allowing 21 independent measurements of the transient secondary magnetic field. Data were collected over target locations statically, such that one data point was collected for each target selected for investigation. Sky personnel collected MetalMapper data over 2,370 targets at the site, pre-processed the data, and submitted background corrected .CSV files for each target to ESTCP, who then forwarded the files to Parsons.

The 2,370 data files were inverted and analyzed using the UX-Analyze add-on to Geosoft's Oasis Montaj software package. Once analysis was complete, theoretical ranked dig lists (theoretical because all targets were intrusively investigated regardless of the indicated stop dig points) were submitted for scoring by the Institute for Defense Analyses. Dig list scoring was based on the number of targets of interest (TOI) correctly identified as items that should be dug and the number of non-TOI or clutter items that were correctly classified as items that did not need to be intrusively investigated. Dig lists submitted by Parsons were scored against the ground truth data generated during the intrusive investigation performed at the site following MetalMapper data collection. Parsons submitted two ranked dig lists for this project. Both dig lists correctly identified all of the TOI on site as TOI, so the only distinction between the two was the amount of clutter correctly classified as clutter. The better performing of the lists reduced the amount of clutter that needed to be intrusively investigated by approximately 79 percent, and the other reduced the clutter digs by approximately 73 percent.

Parsons became familiar with UX-Analyze software used for processing and analyzing the MetalMapper data on data from two previous projects. There had been no major changes to the software between projects, and no implementation issues were noted during processing.

1.0 INTRODUCTION

Currently up to 90 percent of excavation costs on most unexploded ordnance (UXO) / munitions and explosives of concern (MEC) projects are related to removing scrap metal that does not represent an explosive hazard. Significant cost savings could be achieved through the use of geophysical discrimination methods that could reduce the number of excavations required to remove explosive hazards from sites. The objective of this project is to demonstrate the use of advanced electromagnetic induction (EMI) sensors in static data acquisition mode and associated analysis software. To achieve these objectives, a controlled test was conducted at the former Pole Mountain Target and Maneuver Area (PMTMA).

1.1 BACKGROUND

The Fiscal Year 2006 defense appropriation contained funding for the "Development of Advanced, Sophisticated Discrimination Technologies for Unexploded Ordnance Cleanup." The Environmental Security Technology Certification Program (ESTCP) responded by conducting the UXO discrimination study at the former Camp Sibert, Alabama. The results of this first demonstration were very encouraging. The conditions for discrimination were favorable at this site and included a single target-of-interest (4.2-inch [in.] mortar) and benign topography and geology. All of the classification approaches demonstrated correctly identified a sizable fraction of the anomalies as arising from nonhazardous items that could be safely left in the ground. Both commercial and advanced sensors produced very good results. Camp San Luis Obispo (SLO), California, was the site for the second study, which provided greater challenges in topography and a wider mix of targets of interest (TOI). Again, the results were very positive, with increased discrimination of TOI versus nonhazardous items. In 2010 and early 2011, the third, fourth, and fifth ESTCP studies were conducted at the former Camp Butner, North Carolina, the former Mare Island Naval Shipyard, California, and former Camp Beale, California, which all included smaller TOI. Great success was achieved identifying 37-millimeter (mm) projectiles, fuzes, and larger TOI at Camp Butner and Camp Beale with the advanced sensors. Mare Island results are currently unavailable.

To build upon the success of earlier studies, ESTCP sponsored a sixth study in 2011 at a site with a wide range of TOI and variable terrain. The selected range at the former PMTMA included approximately 50 acres of open field potentially contaminated with ordnance ranging in size from 37mm to 3in. projectiles and mortars.

1.2 OBJECTIVES OF THE DEMONSTRATION

This type of approach has the potential to reduce the number of excavations required to effectively remove the explosive safety risk (MEC) at a given site, which would result in significant cost savings related to the closure of formerly used defense sites. The cost savings are expected to be particularly significant at removal action sites. Parsons is currently involved with U.S. Army Corps of Engineers on several MEC and recovered chemical warfare material sites that could be used for additional testing and refining of the process required for this type of discrimination approach.

This demonstration consisted of the cued interrogation of previously identified EM61-MK2 anomalies using the MetalMapper advanced EMI sensor. The objective of the MetalMapper data collection and analysis was to accurately classify each of the targets as either a TOI, likely representing UXO, or non-TOI, representing another type of anomaly source such as UXO fragments or other metallic clutter. Specific performance objectives were developed for the classification study, including the selection of a dig/no-dig threshold that retained all of the TOI targets while minimizing the number of false alarms, minimizing the number of targets classified as "can't analyze," and estimating target parameters such as location and depth correctly.

1.3 REGULATORY DRIVERS

As part of the cleanup of former Department of Defense (DoD) sites, buy-in is required from regulatory agencies at the federal, state, and local levels. The advancement in classification sensors and their successful deployment at real-world sites needs to be documented for their use to be accepted by the applicable regulatory agencies. Their acceptance of the use of this technology at sites for which they are ultimately responsible will be particularly important with the potential for DoD budget cuts to affect the amount of money that will be available for future remedial actions.

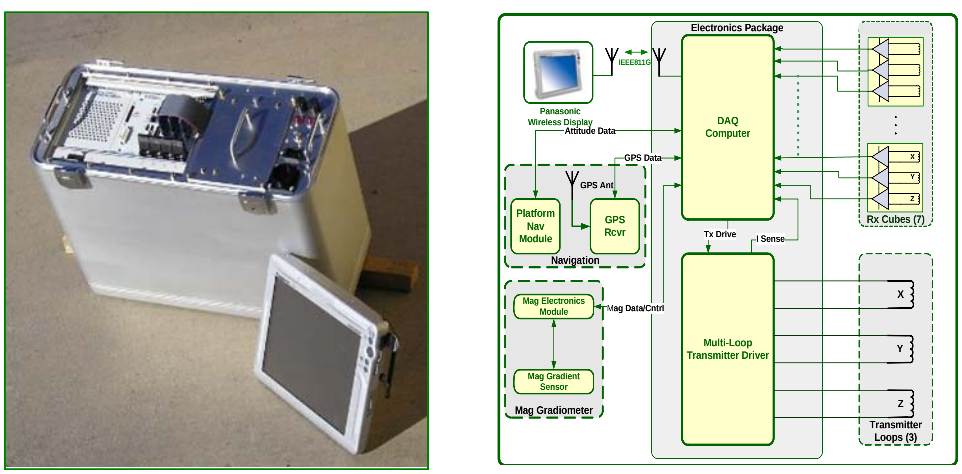
2.0 TECHNOLOGY

2.1 TECHNOLOGY DESCRIPTION

The MetalMapper is an advanced EMI system developed by Geometrics, Inc., with support from the ESTCP. The MetalMapper draws elements of its design from advanced systems currently being developed by G&G Sciences, Inc. (supported by Naval Sea Systems Command, the Strategic Environmental Research and Development Program [SERDP], and ESTCP), and by the Lawrence Berkeley National Laboratory (LBNL) with support from SERDP and ESTCP. It has three mutually orthogonal transmit loops in the Z, Y, and X directions and contains seven tri-axial receiver antennas inside the Z (bottom) loop. Typically, the transmit loops are driven with a classical bipolar pulse-type time domain electromagnetic waveform (i.e., alternating pulse polarity with a 50% duty cycle). Depending on the survey mode (e.g., Static/Dynamic), the fundamental frequency of transmission can be varied over the range $1.11 \leq f \leq 810$ hertz (Hz). The seven receiver antennas allow 21 independent measurements of the transient secondary magnetic field.

The data acquisition computer (DAQ) is built around a commercially available product from National Instruments. The National Instruments DAQ is a full-featured PC running Windows 7. The DAQ, electromagnetic transmitter, and batteries for the system are packaged in an aluminum case that can be mounted on a pack frame, on a separate cart such as a hand truck, or on the survey vehicle such a tractor. The instrumentation package also includes two external modules that provide real-time kinematic global positioning system location and platform attitude (i.e., magnetic heading, pitch, and roll) data. These modules are connected to the DAQ through serial RS232C ports. A block diagram of the DAQ system is shown in **Figure 2-1**.

Figure 2-1: DAQ and DAQ Functional Block Diagram

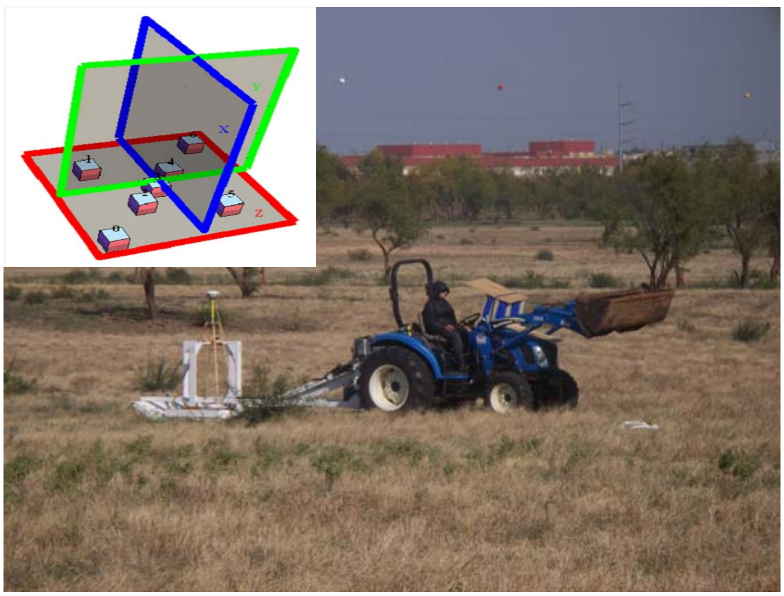


A) MM DAQ assembly with Panasonic terminal. **B) Function block diagram of MM system**

The MetalMapper has two modes of data collection, dynamic and static. Data collected in dynamic mode result in data files containing many data samples. Generally speaking, dynamic mode data are collected while the antenna platform is in motion. Static mode data collection is employed for cued surveys. As its name implies, the antenna platform remains static or motionless during the period of data acquisition. Depending on the acquisition parameters (e.g., sample period and stacking parameter) it can take tens of seconds to complete a static measurement. The results of the static measurement are written into a binary data file containing only a single data point representing the average (stacked) result, usually over tens or even hundreds of repetitions of the transmitter's base frequency.

Data are acquired in time blocks that consist of a fixed number of transmitter cycle "repeats". Both the period and the repeat factor are operator selectable and are varied in multiplicative factors of 3. The MetalMapper also averages an operator-specified number of acquisition blocks (NStacks) together before the acquired data are saved to disk. The decay transients received during the off times are stacked (averaged) with appropriate sign changes for positive and negative half cycles. The decays in an individual acquisition block are stacked, and the decays in that block are averaged with other acquisition blocks (assuming the operator has selected NStack greater than 1). The resultant data are saved as a data point. A photo of the typical configuration of the instrument used for collecting cued data is shown in **Figure 2-2**.

Figure 2-2: Antenna Array and Typical Deployment of the MetalMapper System



In its present (third generation) form, the MetalMapper technology has been demonstrated and scored at the Standardized UXO Technology Demonstration sites at Yuma Proving Grounds (Blind Grid only), at Aberdeen Proving Grounds (Blind Grid plus Direct Fire and Indirect Fire Areas), and most recently at SLO, Camp Butner, and Camp Beale in connection with 2009 through 2011 Classification Studies carried out by ESTCP. The performance of the MetalMapper at these sites is documented in formal reports issued by the Aberdeen Test Center and by the various demonstrators who analyzed the data collected at SLO, Camp Butner, and Camp Beale.

2.2 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

There are a few advanced EMI sensors that are similar to the MetalMapper in theory and design, with the most comparable being the Naval Research Laboratory's TEMTADS 5x5 and the LBNL Berkeley UXO Discriminator (BUD). The TEMTADS 5x5 consists of 25 pairs of transmit/receive coils oriented in a 5x5 grid pattern, approximately 2 meters (m) to a side. The BUD is composed of three orthogonal transmitters and eight pairs of differenced receivers. These instruments have been part of the ongoing ESTCP Classification Demonstrations, and similar results have been documented for all three during previous projects. The main advantage of the MetalMapper is that it is currently commercially available, while the other two are generally only used by the organizations that developed them and are very limited in number.

The greatest limitation of the MetalMapper is its size, both of the sensor itself and of the accompanying computer, screen, and cables. The system is designed primarily for use in relatively flat, open fields and cannot currently be used effectively in wooded areas. Additionally, its effectiveness in areas with extremely high anomaly densities is currently unknown, although data were collected in high anomaly density areas during a demonstration study at performed Fort Sill in late 2011. Results for this study are currently unavailable.

3.0 PERFORMANCE OBJECTIVES

The primary performance objectives for this demonstration include:

- Evaluating whether classification techniques will work at the former PMTMA site;
- Evaluating where classification techniques will work at former PMTMA; and
- Evaluating the cost effectiveness of classification techniques in the areas at the former PMTMA where classification is determined to be effective.

The specific performance objectives for this demonstration are based on the objectives stated in the project demonstration plan (Parsons, 2011) and are summarized in **Table 3-1**.

Table 3-1. Performance Objectives for this Demonstration

Performance Objective	Metric	Data Required	Success Criteria
Maximize correct classification of targets of interest (TOIs)	Number of TOIs retained	• Prioritized anomaly lists • Scoring reports from Institute for Defense Analyses (IDA)	Approach correctly classifies all TOIs
Maximize correct classification of non-TOI	Number of false alarms eliminated	• Prioritized anomaly lists • Scoring reports from IDA	Reduction of false alarms by > 50% while retaining all targets of interest
Specification of no-dig threshold	Probability of correct classification and number of false alarms at demonstrator operating point	• Demonstrator-specified threshold • Scoring reports from IDA	Threshold specified by the demonstrator to achieve criteria above
Minimize number of anomalies that cannot be analyzed	Number of anomalies that must be classified as “Unable to Analyze”	• Demonstrator target parameters	Reliable target parameters can be estimated for > 98% of anomalies on each sensor’s detection list.
Correct estimation of target parameters	Accuracy of estimated target parameters	• Demonstrator target parameters • Results of intrusive investigation	X, Y < 15 cm (1σ) Z < 10 cm (1σ)

3.1 OBJECTIVE: MAXIMIZE CORRECT CLASSIFICATION OF TOI

One of the two main objectives of this demonstration was to correctly classify all seeded items and any MEC items remaining at the site as TOI.

3.1.1 Metric

The metric for this objective was the number of items on the MetalMapper anomaly list correctly classified as TOI.

3.1.2 Data Requirements

MetalMapper data were analyzed to create a prioritized dig list, which assigned each target to one of three categories: 1) TOI, 2) non-TOI, or 3) can't analyze. The targets classified as either TOI or "can't analyze" were considered "dig" targets. The Institute for Defense Analyses (IDA) used scoring algorithms to compare the "dig" targets to the list of items identified as TOI during the intrusive survey.

3.1.3 Success Criteria

The objective is considered met if all items of interest are correctly labeled as TOI on the prioritized anomaly list.

3.2 OBJECTIVE: MAXIMIZE CORRECT CLASSIFICATION OF NON-TOI

This is the second of the two primary measures of the effectiveness of the classification approach. In addition to correctly classifying TOI, the effectiveness of the MetalMapper in discriminating munitions is a function of the degree to which responses that do not correspond to TOI can be eliminated from consideration during the intrusive investigation.

3.2.1 Metric

The metric for this objective was the number of targets on the ranked anomaly list created using the MetalMapper data that were correctly classified as non-TOI.

3.2.2 Data Requirements

MetalMapper data were analyzed to create a prioritized dig list, which assigned each target to one of three categories: 1) TOI, 2) non-TOI, or 3) can't analyze. The targets classified as non-TOI were considered "no dig" targets. IDA used scoring algorithms to compare the "no dig" targets to the list of items identified as non-TOI during the intrusive survey.

3.2.3 Success Criteria

The objective is considered met if more than 50% of the non-TOI items can be correctly labeled as non-TOI.

3.3 OBJECTIVE: SPECIFICATION OF NO-DIG THRESHOLD

In a retrospective analysis as performed in this demonstration, it is possible to tell the true classification capabilities of a classification procedure based solely on the ranked anomaly list submitted. In a real-world scenario, all targets may not be dug, so the success of the approach will depend on the ability of an analyst to accurately specify its dig/no-dig threshold.

3.3.1 Metric

The probability of correct classification and the number of false alarms at the dig/no dig threshold in the prioritized dig list are the metrics for this objective.

3.3.2 Data Requirements

Following data collection, MetalMapper data were analyzed to create a prioritized dig list, which assigned each target to one of three categories: 1) TOI, 2) non-TOI, or 3) can't analyze. The category into which each target is placed was determined using a decision statistic developed during analysis of the MetalMapper data. The dig/no dig threshold for this project was the decision statistic value that separates targets classified as TOI from those classified as non-TOI. IDA personnel used its scoring algorithms to assess the results.

3.3.3 Success Criteria

The objective is considered met if more than 50% of the non-TOI items can be correctly labeled as non-TOI while retaining all of the TOI at the specified threshold.

3.4 OBJECTIVE: MINIMIZE NUMBER OF ANOMALIES THAT CANNOT BE ANALYZED

Anomalies for which reliable parameters cannot be estimated using the collected MetalMapper data cannot be classified. These anomalies must be placed in the dig category, which reduces the effectiveness of the classification process.

3.4.1 Metric

The number of anomalies for which reliable parameters cannot be estimated is the metric for this objective.

3.4.2 Data Requirements

Those targets for which parameters could not be reliably estimated were identified as such on the prioritized dig list submitted following analysis of the MetalMapper data.

3.4.3 Success Criteria

The objective is considered met if reliable parameters can be estimated for > 98% of the targets on the prioritized dig list.

3.5 OBJECTIVE: CORRECT ESTIMATION OF TARGET PARAMETERS

This objective involves the accuracy of the target parameters that are estimated in the first phase of the analysis. Successful classification is only possible if the input features are internally consistent. The obvious way to satisfy this condition is to estimate the various target parameters accurately.

3.5.1 Metric

Accuracy of estimation of target parameters is the metric for this objective.

3.5.2 Data Requirements

The inverted or fit locations determined for each target during MetalMapper analysis and the locations of recovered items, as recorded by the intrusive teams, were compared to determine the difference between the two.

3.5.3 Success Criteria

The objective is considered to be met if the estimated X, Y locations are within 15 centimeters (cm [1σ]) of the actual locations and if the estimated depths are within 10 cm (1σ).

4.0 SITE DESCRIPTION

As Parsons personnel were did not perform any of the on-site tasks for this project, limited site information is available. The following was taken from the ESTCP Live Site Demonstrations Plan for the former PMTMA (ESTCP, 2011). The former PMTMA is a 62,448.15 acre site located in Laramie, WY. The demonstration was conducted in the Bisbee Hill Maneuver Area. An aerial photo of the demonstration area is shown in **Figure 4-1**.

4.1 SITE SELECTION

This site was chosen as the next in a series of sites for demonstration of the classification process. The first site in the series, former Camp Sibert in Alabama, had only one TOI and item "size" was an effective discriminant. A hillside range at the former Camp San Luis Obispo in California was selected for the second of these demonstrations because of the wider mix of munitions, including 60-mm, 81-mm, and 4.2-in mortars and 2.36-in rockets. Three additional munitions types were discovered during the course of the demonstration. The third site chosen was the former Camp Butner in North Carolina. This site is known to be contaminated with items as small as 37-mm projectiles, adding yet another layer of complexity into the process. The fourth site, the former Mare Island Naval Shipyard (MINS) in Vallejo, CA, was selected because of an opportunity in the Navy's remediation schedule at MINS to conduct the study in the midst of their ongoing munitions response project and prior to the upcoming removal action in 2012. The fifth site, Camp Beale in Yuba, CA, was selected for demonstration because it is partially wooded and is thought to contain a wide mixture of munitions.

The demonstration site totaled approximately 50 acres. The EM61 cart surveyed the entire site with the exception of the fenced area in the upper left part of the site. The demonstration site is shown in **Figure 4-2**. This site was selected because of its wide mixture of munitions and variable terrain. The smallest known munition on the site is the 37-mm projectile, the largest known items are 3-inch projectiles and mortars, with a range of munition sizes in between.

4.2 SITE HISTORY

The PMTMA was established in 1879 as the Fort D.A. Russell Wood and Water Reserve. The land status alternated between national forest and military reservation from 1897 to 1925. The Pole Mountain area has also been known as the Crow Creek Forest Reserve, Fort D.A. Russell Target and Maneuver Range, Fort Francis E. Warren Target and Maneuver Range, Pole Mountain Reservation, Pole Mountain Training Annex, and Warren Training Annex. It was extensively used before 1959 as a target and maneuver area by the Army, the Reserve Officers' Training Corps, the Citizens' Military Training Corps, various National Guard units, and the Department of the Air Force.

4.3 SITE GEOLOGY

Site specific geologic information was not included in the ESTCP demonstration plan. However, near surface geologic conditions were not expected to adversely impact the functionality of either the EM61-MK2 or the MetalMapper. No significant geologic effects were noticeable in the MetalMapper data collected during the project.

Figure 4-1: Location of Demonstration Site

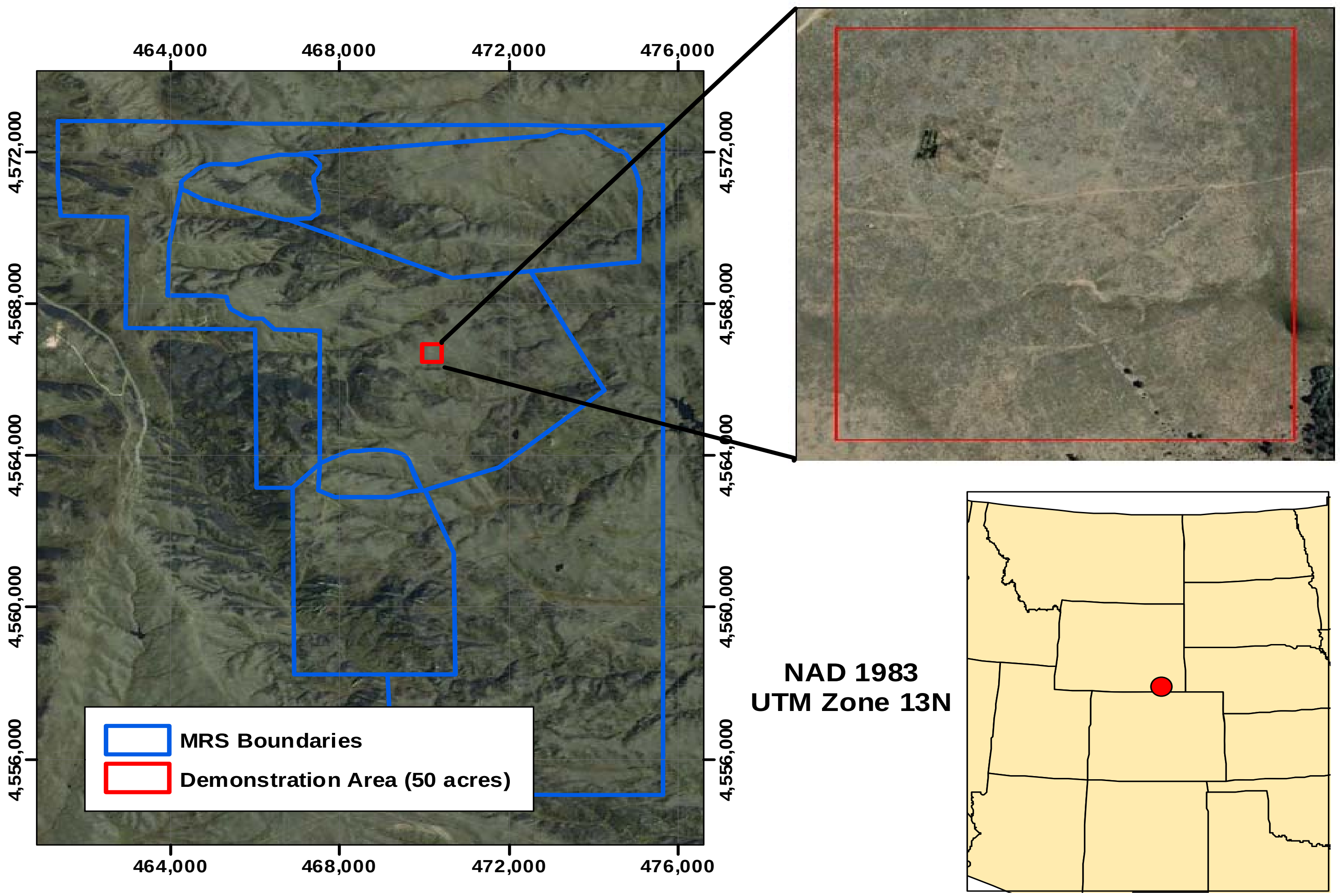
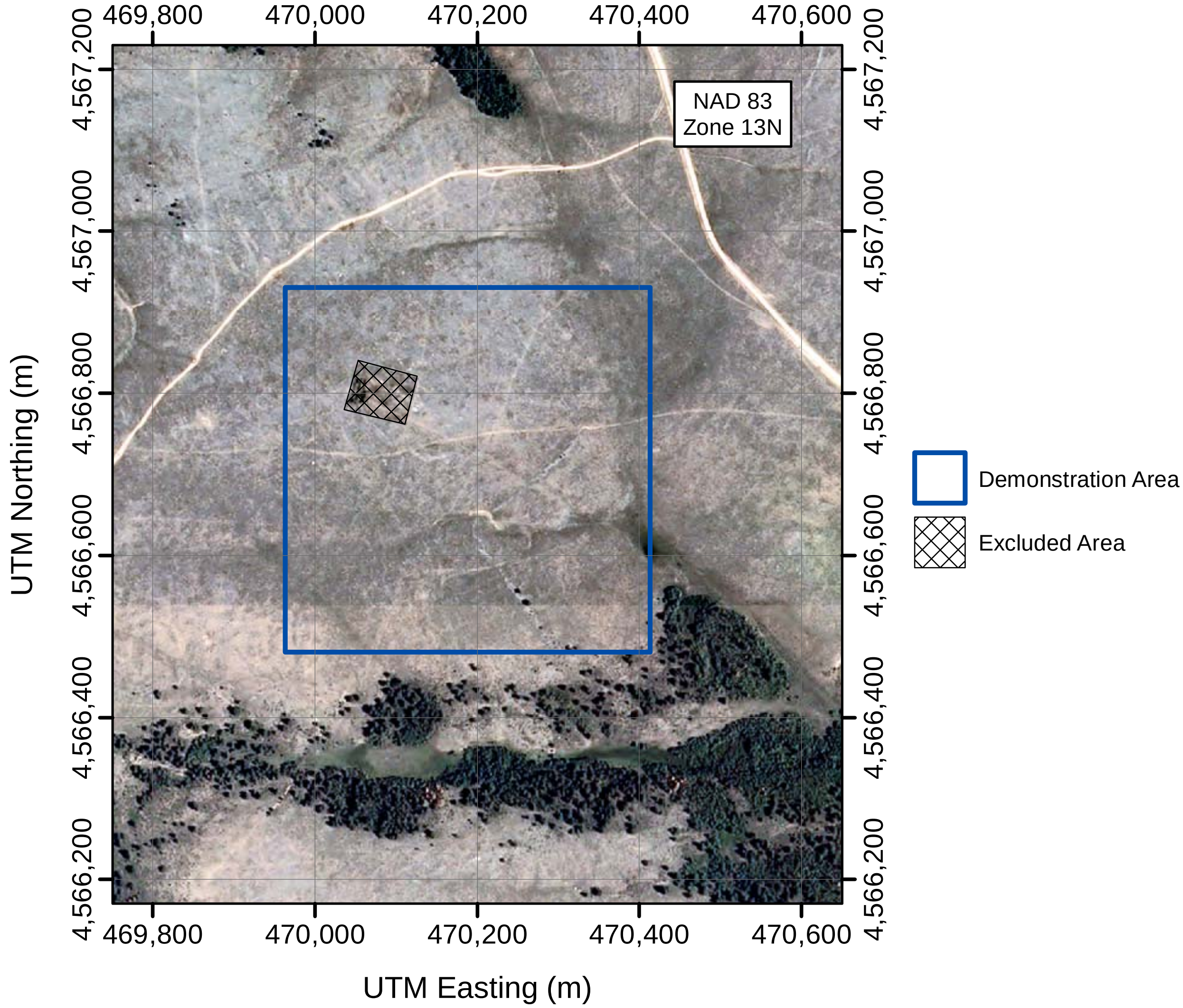


Figure 4-2: Aerial Photograph of the Demonstration Site



4.4 MUNITIONS CONTAMINATION

A large variety of munitions have been reported as used at PMTMA. Physical evidence for the following items was discovered during the RI:

- Projectiles containing high explosive (HE) filler (37-mm to 155-mm, and 2.95-inch);
- Shrapnel projectiles (75-mm and 3-inch);
- 37-mm projectiles (inert and unfuzed)
- 3-inch Stokes mortars (practice, fuzed);
- 60-mm mortars containing HE filler; and
- Small arms ammunition (.30-caliber and .50-caliber)

5.0 TEST DESIGN

5.1 CONCEPTUAL EXPERIMENTAL DESIGN

The objective of this program was to demonstrate a method for the use of classification in the munitions response process. The three key components of this method are 1) collection of high-quality geophysical data and principled selection of anomalous regions in those data, 2) analysis of the selected anomalies using physics-based models to extract target parameters such as size, shape, and materials properties, and 3) the use of those parameters to construct a ranked anomaly list. Each of these components was handled separately in this program, with different contractors responsible for different tasks. Parsons was only responsible for the processing and analysis of data collected by another contractor. Target parameters extracted during processing were passed through classification routines that were used to produce prioritized anomaly lists ordered from the item that the classification routine determined was most likely a munition through the item regarded as the most likely to be nonhazardous.

Validation digging was also coordinated by the Program office. The prioritized anomaly lists were scored by the IDA, with emphasis on the number of items correctly labeled nonhazardous while correctly labeling all TOIs.

The primary objective of the demonstration was to assess how well each demonstrator was able to order its ranked anomaly list and specify the threshold separating high-confidence clutter from all other items. The secondary objective was to determine the classification performance that could be achieved by each approach through a retrospective analysis.

5.2 SITE PREPARATION

Parsons was not involved in site preparation for this project. Site set-up and logistics were performed by URS Corporation, and details regarding this aspect of the project should be contained in their report.

5.3 SYSTEM SPECIFICATION

The MetalMapper sensor and data acquisition system are described in detail in Section 2.1. All MetalMapper data for this project were collected by Sky Research, Inc. (Sky). Site-specific MetalMapper configuration should be discussed in detail in Sky's report.

5.4 CALIBRATION ACTIVITIES

All MetalMapper data for this project were collected by Sky. Any MetalMapper calibration activities performed on site should be discussed in detail in Sky's report.

5.5 DATA COLLECTION PROCEDURES

All MetalMapper data for this project were collected by Sky. Specific data collection activities performed on site should be discussed in detail in Sky's report.

5.6 VALIDATION

All anomalies on the master list were excavated by a team led by the URS Corporation. At the conclusion of data collection activities, all anomalies on the master dig list were excavated. Each item encountered was identified, photographed, its depth measured, its location determined using cm-level GPS (global positioning system), and the item removed if possible. These ground truth data were used for evaluation of the dig lists submitted by various analysts.

6.0 DATA ANALYSIS AND PRODUCTS

The MetalMapper was used to collect static data over 2,370 targets identified at the former PMTMA based on EM61-MK2 data. The processing and analysis steps that were used to generate a dig/no dig decision for each target are described below.

6.1 PREPROCESSING

Raw MetalMapper data are collected and stored as .TEM files. The MetalMapper acquisition software uses a convention for assigning a unique name to each data file without the need to manually enter the name. The operator supplies a prefix for the root name of the file (e.g., “Static”). The acquisition software then automatically appends a five-character numerical index to the filename prefix to form a unique root name for the data file (e.g., Static00001). The index is automatically incremented after the file has been successfully written. Although the Target identification (ID) is not used as the file name in the .TEM file, the Target ID is stored in the file according to name of the target highlighted on the MetalMapper screen during collection.

Pre-processing of the .TEM files was performed by Sky personnel; it consisted of removing background values from the data, converting the points from the geographic coordinate system used for collection to the Universal Transverse Mercator Zone 13N coordinate system used for processing, and exporting the resulting data to a .CSV file that could be imported into the UX-Analyze package in Geosoft’s Oasis Montaj software. The exported .CSV file name contained both the collection ID and the Target ID (e.g., 2621_Static00001_2621).

6.2 PARAMETER ESTIMATION

All MetalMapper data points were inverted using UX-Analyze to determine modeled parameters for each target. These parameters included the location, size, and orientation of the source object; the polarizability of each axis of the object; and information regarding the quality of the data and the relative match between the inverted data and the expected model.

All target inversion was initially performed using the UX-Analyze batch processing mode with the multiple object solver enabled. Targets for which multiple objects were identified using the multiple object solver were re-inverted using the batch processor without the multiple object solver enabled. In these cases, the single object and multiple object results were compared to determine which method returned a result more indicative of TOI. Although the multiple object result may have approximated the expected model to a higher degree, the result more indicative of potential TOI was used for target ranking to be conservative.

6.3 CLASSIFIER AND TRAINING

6.3.1 Confidence Metrics

The polarization curves developed for each target, including any single-object-only results and secondary multiple-object results, were compared to a library of known polarization curves compiled using test stand data and test pit data from the former PMTMA. The items in the comparison library were limited to the TOI expected at the PMTMA site: 37mm, 75mm, 105mm, and 155mm projectiles; 60mm, 81mm, and Stokes mortars; and small industry standard objects (ISOs). Examples of various types of these items were used (e.g., six different versions of 37mm projectiles, three types of 81mm mortar), but items not expected at the site, such as hand grenades and rockets, were not included. All initial comparisons between the measured targets and the library data were also performed using an equal weight for all three primary polarizabilities (size: 1, shape 1: 1, shape 2: 1). The classification results for each target were then examined by the data processor.

The first examination of the classification results was performed to determine the usability of each result. The processor either determined that the results were usable as they were or made a note in the target database in Geosoft that further processing was necessary. Results were deemed usable if the reviewer identified three reasonable-looking polarization curves or if a curve for the primary axis of polarization (β1) could not be identified. In these cases, the target was either left for ranking according to the decision statistic developed for the project (Section 4.0) or, for those targets without an identifiable β1 curve, classified as "can't analyze." While the data for "can't analyze" targets were not usable for classification purposes because UX-Analyze cannot effectively compare a target without a primary polarizability to the library data, the result for that target was considered "usable" in that no further analysis would be performed on that target.

Targets with results not necessarily deemed usable on the first pass included those for which one or more non-β1 curves appeared to be poor data for any reason or targets that appeared to be "ordnance-like" but did not have a particularly good match to any of the library objects. "Ordnance-like" was defined as an object with relatively equal (i.e., symmetric) secondary axes of polarizability (β2 and β3) for which the magnitude of β1 was not less than β2 and β3. It was considered possible that targets with these characteristics were examples of ordnance not expected at the site and, therefore, not in the comparison library. **Figure 6-1** shows examples of the types of targets flagged during the first examination of the data: one with poor results for multiple polarization curves, and one that appears symmetric but with a poor match to any library object.

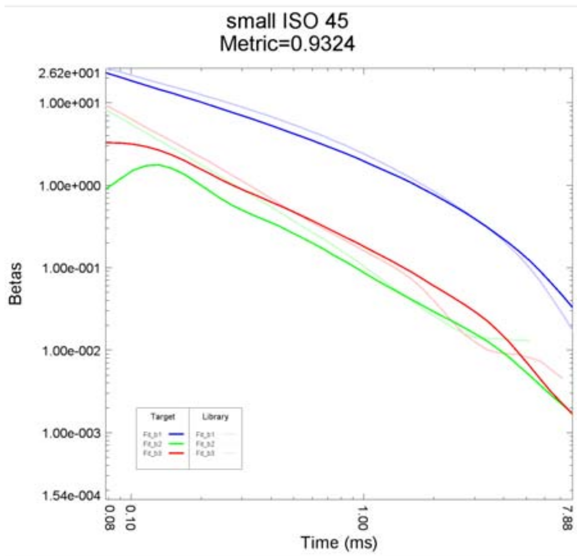
Targets with one or more apparently poor β2 or β3 curves, as shown in Figure 6-1A, were re-compared to the library data with the poor curves removed from the comparison. This was accomplished by changing the comparison weight for the poor-quality data to 0 (size: 1, shape 1: 1, shape 2: 0; or size: 1, shape 1: 0, shape 2: 0). In these cases, the revised, β1/β2- or β1-only-based confidence metrics were used when calculating the decision statistic used to rank each target.

6.3.2 Training Data

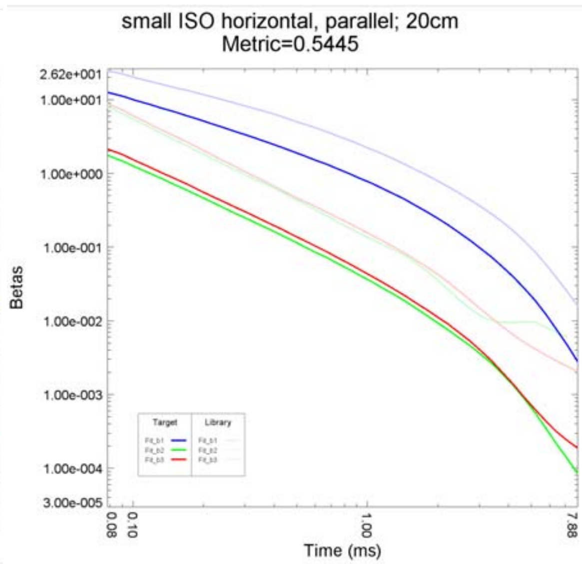
The training data request for the former PMTMA comprised targets flagged as "ordnance-like," as described above. Various examples of these items were added to a separate target library and compared to the other symmetric objects, with the end result that seven items added to the library fit all of the others with a confidence of 0.75 or higher. Nine examples of these items or items closely matching them were requested as training data. None of the requested targets were identified as a TOI, so the original PMTMA library was not modified based on the results of the training data.

Figure 6-1: Targets Flagged for Additional Processing

A: β3 curve appears to be poor data



B: Target is symmetric, but poor metric



6.3.3 Decision Statistic

Classification for the PMTMA project was accomplished using the confidence metrics generated for each target during the comparison to the library data. Two dig lists were submitted for the project. For the first, the confidence metric calculated for all three curves was used unless poor curves were identified by the analyst, as described in Section 3.3. In that event, the metric calculated for the β1/β2- or β1-only matches was used. The decision statistic used for the project was simply the final confidence metric selected for each target (β1/β2/β3, or β1/β2- or β1-only). No additional weight was given to targets that had three usable curves rather than one- or two-only, as there were relatively few targets for which less than three curves were used. Targets were ranked based on decreasing confidence that they were TOI.

For the second list, targets were prioritized according to a combination of β1/β2/β3, β1/β2-, and β1-only confidence metrics prior to ranking. Priorities ranged from 4 (high) to 0 (low) for all non-training/non-can't analyze targets, and the decision statistic was a sum of the priority plus the β1/β2/β3 confidence metric. Each dig list was completed in three stages as described below.

6.4 DATA PRODUCTS

6.4.1 Dig List 1

As discussed in Section 6.3.3, the decision statistic for the first list was based solely on the final confidence metric selected for each target regardless of the number of polarization curves used in the match. The decision statistic was equal to the confidence metric, and targets were ranked from high decision statistic to low.

6.4.1.1 Dig List 1 Stage 1

The first stage dig list was submitted with the following parameters:

- Training Data: 9 items selected as described in Section 3.4
- Can't Analyze: 164 items without usable β1 curves
- Likely TOI (Category 1): Decision statistic greater than 0.700
- Cannot Decide (Category 2): Decision statistic between 0.600 and 0.700
- Likely Clutter (Category 3): Decision statistic less than 0.600

The stop dig threshold was set at a decision statistic of 0.650 (mid-Category 2), with the training data and "can't analyze" targets also considered digs. The Stage 1 dig list was only compared to the project seed items identified as QC seeds. This comparison identified two seeds that would have gone un-dug based on the Stage 1 list, PM-155 and PM-1847. PM-155 was a 37mm buried at 18cm with a decision statistic of 0.608; PM-1847 was a small ISO buried at a depth of 30cm with a decision statistic of 0.632. Because both of these targets were un-dug targets within Category 2, the decision was made to extend the dig threshold to the bottom of Category 2 (0.600) for the next stage of the dig list.

6.4.1.2 Dig List 1 Stage 2

The second stage dig list was submitted with the following parameters:

- Training Data: 11 items, including QC Seeds PM-155 and PM-1847
- Can't Analyze: 164 items without usable β1 curves
- Likely TOI (Category 1): Decision statistic greater than 0.600;
- Cannot Decide (Category 2): Decision statistic between 0.600 and 0.550
- Likely Clutter (Category 3): Decision statistic less than 0.550

Modifications between the Stage 1 dig list and the Stage 2 dig list included the addition of the two missed QC seeds to the training data set and the changing of category break points to lower decision statistics based on the non-detection of PM-155 and PM-1847 with the Stage 1 dig list. The Stage 2 dig list was considered an actual dig list, and the full set of intrusive results for the targets marked as "dig" were returned following the submittal. For this list, the stop dig point was set at a decision statistic of 0.575.

The dig results indicated that the lowest ranked TOI was PM-1492, which had a decision statistic of 0.587. The final 19 investigated targets were all non-TOI, so there did not appear to be a reason to modify the dig threshold further for the final, Stage 3 dig list.

6.4.1.3 Dig List 1 Stage 3

The final dig list was submitted with the following parameters:

- Training Data: 11 items, including QC Seeds PM-155 and PM-1847
- Can't Analyze: 164 items without usable β1 curves

- Likely TOI (Category 1): Decision statistic greater than 0.575 – Dig
- Likely Clutter (Category 3): Decision statistic less than 0.575 – Do not dig

The only change between the Stage 2 and Stage 3 dig lists was the elimination of Category 2. Investigated cannot decide targets from Stage 2 were changed to Category 1, and targets with decision metrics between 0.575 and 0.550 (i.e., un-dug Category 2) were changed to Category 3. The final list included 750 digs out of the 2,370 total targets. One hundred and seventy-five of these were either targets used as training data or "can't analyze" anomalies, with the remainder ranked according to the decision statistic. The stop dig threshold was set at rank number 575.

6.4.2 Dig List 2

As discussed in Section 6.3.3, the decision statistic for the second target list submitted for the Pole Mountain project was based on a combination of a priority given to each target and the confidence metric for that target. For the second list, targets were prioritized according to a combination of $\beta 1/\beta 2/\beta 3$, $\beta 1/\beta 2$-, and $\beta 1$-only confidence metrics prior to ranking as follows:

- Priority 4 (highest priority): $\beta 1/\beta 2/\beta 3$ confidence metric greater than 0.80 and $\beta 1$-only confidence metric greater than 0.85
- Priority 3: Non-Priority 4 targets with $\beta 1/\beta 2/\beta 3$ confidence metric greater than 0.60 and $\beta 1$-only confidence metric greater than 0.70
- Priority 2: Non-Priority 3 or 4 targets with $\beta 1/\beta 2/\beta 3$ confidence metric greater than 0.575 and $\beta 1$-only confidence metric greater than 0.70
- Priority 1 (lowest priority): Non-Priority 2, 3, or 4 targets with
  - $\beta 1/\beta 2/\beta 3$ confidence metric greater than 0.575 and $\beta 1$-only confidence metric less than 0.70
  - $\beta 1/\beta 2$-only confidence greater than 0.75 and $\beta 1$-only confidence metric greater than 0.85, provided target is not plate-like (i.e., $\beta 2/\beta 3$ curves are greater than $\beta 1$ curve); added after Stage 1 dig list (prior to Stage 2)

The decision statistic for each target was the sum of the priority plus the $\beta 1/\beta 2/\beta 3$ confidence metric for that target.

6.4.2.1 Dig List 2 Stage 1

The first stage dig list was submitted with the following parameters:

- Training Data: 9 items selected as described in Section 3.4
- Can't Analyze: 167 items without usable $\beta 1$ curves
- Likely TOI (Category 1): Decision statistic greater than 3.0 (Priority 3 and 4 targets)
- Cannot Decide (Category 2): Decision statistic between 1.0 and 3.0 (Priority 1 and 2 targets)
- Likely Clutter (Category 3): Decision statistic less than 1.0

The stop dig threshold was set at a decision statistic of 2.0 (the break point between the Priority 1 and Priority 2 targets in Category 2), with the training data and "can't analyze" targets also considered digs. The Stage 1 dig list was only compared to the project seed items identified as QC seeds. This comparison did not identify any missed QC seeds. However, one of the TOIs was ranked extremely close to the stop dig threshold on this list. Therefore, the decision was made to extend the dig threshold to the bottom of Category 2 (decision statistic greater than 1) for the next stage of the dig list. Items with low β1/β2/β3 but relatively high β2/β3-only and β1-only confidence matches were also added to the dig list as Priority 1 targets.

6.4.2.2 Dig List 2 Stage 2

The second stage dig list was submitted with the following parameters:

- Training Data: 9 items selected as described in Section 3.4
- Can't Analyze: 167 items without usable β1 curves
- Likely TOI (Category 1): Decision statistic greater than 1.0 (all non-0 Priority targets)
- Likely Clutter (Category 3): Decision statistic less than 1.0

As discussed above, for the Stage 2 dig list, all of the un-dug Category 2 targets were re-classified as Category 1, and items with low β1/β2/β3 but relatively high β2/β3-only and β1-only confidence matches were also added to the dig list as Priority 1 targets and classified as Category 1. Nine targets were added to the dig category based on their re-classification.

None of the digs added between the Stage 1 and Stage 2 dig lists were TOI. Therefore, the decision was made to keep the Stage 2 dig list as the final list. Because there were no Category 2 targets in the Stage 2 list, no changes were made for Stage 3. The final list included 634 digs out of the 2,370 total targets. One hundred and seventy-five of these were either targets used as training data or "can't analyze" anomalies, with the remainder ranked according to the decision statistic. The stop dig threshold was set at rank number 458.

7.0 PERFORMANCE ASSESSMENT

7.1 OBJECTIVE: MAXIMIZE CORRECT CLASSIFICATION OF TOI

IDA compared the submitted dig list was compared to ground truth data from PMTMA. The results of the dig list comparisons to the ground truth list were judged according to performance objectives identified for the project in the PMTMA demonstration plan (Parsons, 2011). **Table 3-1** contains the performance objectives and identifies the criteria by which they were judged. The results for the two submitted dig lists with respect to each project objectives are detailed below.

Figure 7-1 shows the receiver operating characteristic (ROC) curve for dig list 1. As indicated in the figure, all TOI were correctly identified, and the performance objective was met.

Figure 7-1: ROC Curve for Dig List 1: Confidence Metric as Decision Statistic

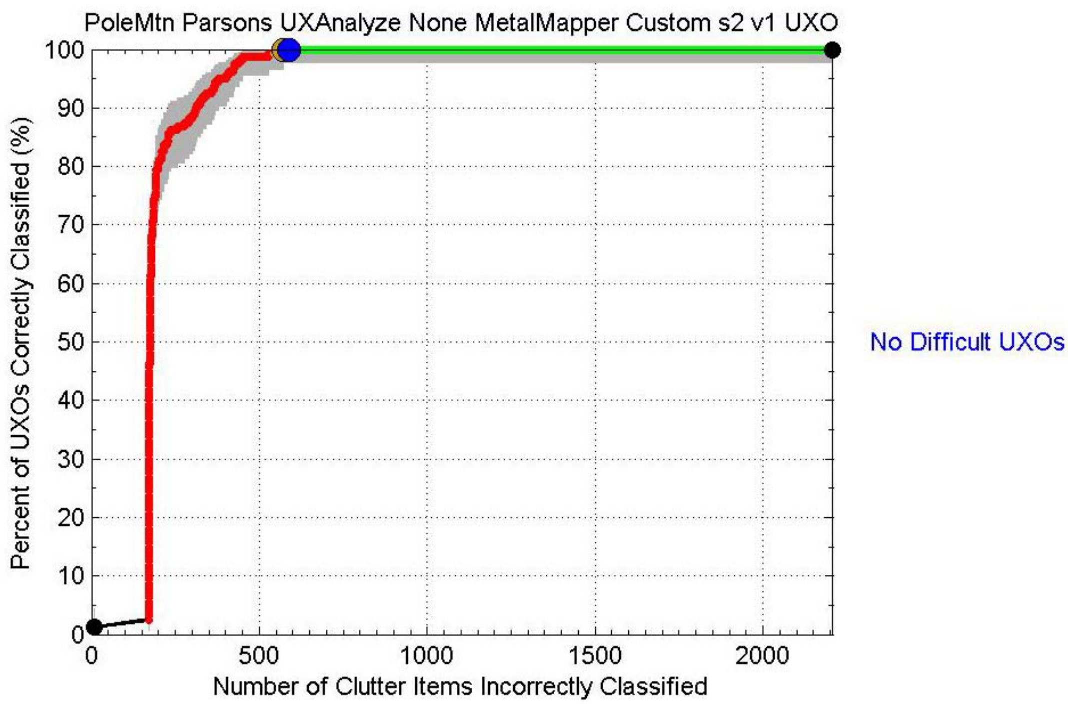
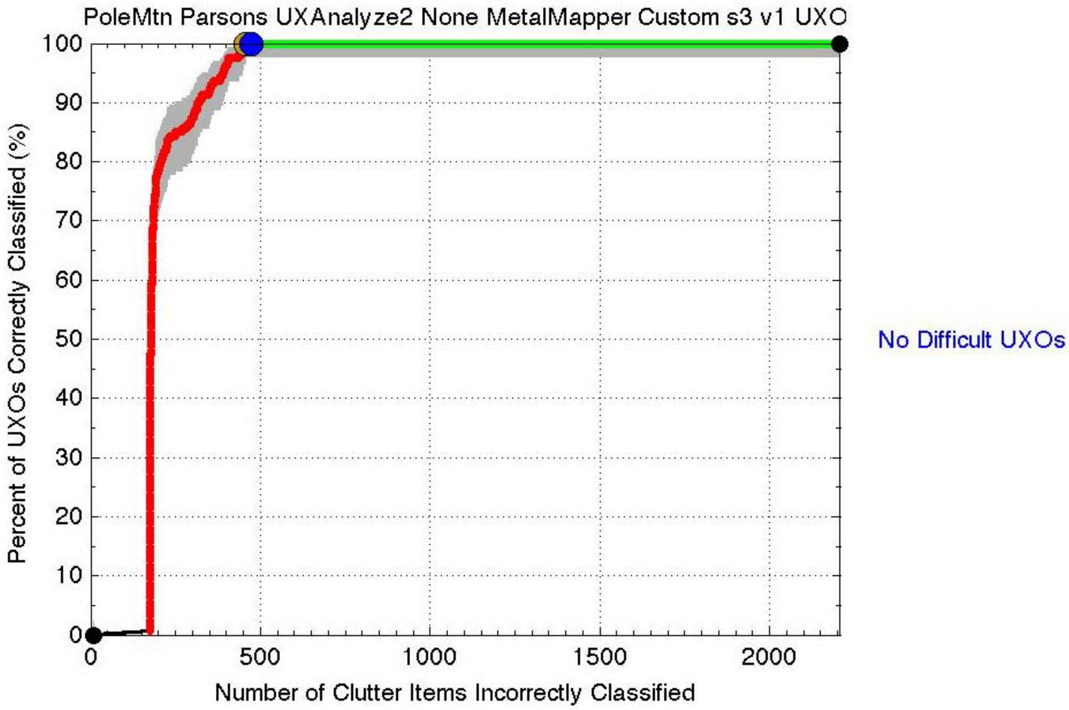


Figure 7-2 shows the ROC curve for dig list 2. As indicated in the figure, all TOI were correctly identified, and the performance objective was met.

7.2 OBJECTIVE: MAXIMIZE CORRECT CLASSIFICATION OF NON-TOI

A few of the 2,370 targets for which data were collected at PMTMA ended up being multiple picks on the same source, so a total of 2,368 digs were performed during the project. This also reduced the number of items in dig list 1 that needed intrusive investigation from 753 to 749 and the number of items in dig list 2 from 634 to 633. The small reduction in targets meant that there were 2,208 true negatives, or clutter items, in the data set.

Figure 7-2: ROC Curve for Dig List 2: Prioritized Targets



Dig list 1 correctly identified 73.3 percent (1,619 of 2,208) of the clutter items as clutter, and dig list 2 correctly identified 78.5 percent (1,735 of 2,208) of the clutter items as clutter. Both versions are well above the performance objective of reducing the number of false alarms by greater than 50 percent.

7.3 OBJECTIVE: CORRECT SPECIFICATION OF NO-DIG THRESHOLD

For both dig lists submitted, all TOI at the site were correctly identified as TOI, and the number of false positives was reduced by more than 50 percent of the total number of false positives. These exceed the performance objectives for the dig threshold, so both lists have passed this performance criterion.

7.4 OBJECTIVE: MINIMIZE NUMBER OF ANOMALIES THAT CANNOT BE ANALYZED

The same “can’t analyze” list, which contained 167 targets, was used for both dig lists submitted. This corresponds to approximately 7 percent of the targets at the site and exceeds the 2 percent limit specified in the performance objectives. As discussed in Section 3.3, all targets without a usable β1 curve were classified as “can’t analyze” in the PMTMA data set. It is expected that additional data examination, including an analysis of the signal amplitude and offset between the picked and collected point locations, is likely to reduce the number of “can’t analyze” targets required. Using this strategy, potential “can’t analyze” targets with low signal amplitude collected where they should have been collected (i.e., likely indicative of poor EM61 data for the original target) would be considered good MetalMapper data despite poor β1 curves.

7.5 OBJECTIVE: CORRECT ESTIMATION OF TARGET PARAMETERS

The target parameters estimated in this case were the X, Y, and relative Z (depth) coordinates of the targets. Because the goal with this objective is to direct the dig teams to the correct locations for TOI, the comparison of estimated coordinates to actual coordinates was only performed for TOI and for those targets marked as digs in the ranked dig list. Dig list 2, the list that eliminated more of the true negatives from dig consideration, was used for the comparison.

The success criteria for this performance objective were X, Y offsets for which one standard deviation of the dataset was less than 15cm and depth offsets for which one standard deviation of the data set was less than 10cm. The performance objective was passed for the TOI comparison, with calculated standard deviations of 11.1cm for the horizontal offset and 6.5cm for the vertical offset. The results for all of the targets marked as digs were above the criteria for both the horizontal and vertical offsets, with a calculated horizontal offset standard deviation of 33.7cm and a vertical offset standard deviation of 10.8cm.

In the comparisons, the modeled location of the target was the fit X, Y, and Z coordinates while the actual location was defined as the closest measured location to the fit location. This only mattered in the case of targets for which multiple objects were recovered from the vicinity of the picked location. However, much of the discrepancy seen in the X, Y locations for all of the “dig” targets is likely due to multiple-object locations being modeled as single objects during inversion. There does not seem to be a ready solution to the slight discrepancy between the performance objective and the results for the “dig” targets, although the results for the TOI were positive.

8.0 COST ASSESSMENT

8.1 COST MODEL

The cost model for the former PMTMA demonstration includes the cost of processing and analysis for the MetalMapper data collected by Sky. Costs were broken down into three categories: processing, analysis, and dig list compilation. Processing and analysis time for each task was measured to the nearest 15-minute interval.

Table 8-1. MetalMapper Processing and Analysis Costs

Cost Element	Data Tracked during Demonstration	Costs
MetalMapper Data Processing and Analysis		**$3.23/target**
Processing	Time required to perform inversion of each target using UX-Analyze and to create polarization curve figures for each	1.5 min/target
Analysis	Time required to examine polarization curves for each target, identify unknown items for training data request, finalize confidence metrics, and import results into Access database	1 min/target
Dig List Compilation	Time required to organize and submit two ranked dig lists	0.2 min/target

8.2 COST DRIVERS

Based on the factors described above, the total per-target cost for the processing and analysis of the MetalMapper targets collected at the former PMTMA was $3.23. It is expected that this cost is on the low end of what could be expected for a typical classification project, based on the relative ease of this site with respect to the types of ordnance expected at the site (few and large) and with Parsons' relative inexperience with processing and analyzing MetalMapper data. Although the results of this demonstration were positive with respect to the performance objectives, additional experience with this type of data has identified additional processing and analysis steps that may have eliminated a greater number of clutter items from the dig category on both ranked dig lists. Examples of additional processing/analysis that would potentially improve the demonstration results include the calculation and analysis of signal amplitude and collection location versus pick location to reduce the number of "can't analyze" targets, as described in Section 7.4, and the creation and use of parameter space plots as a resource to potentially identify targets that might need to be added to or removed from the dig category based on size and decay characteristics.

9.0 IMPLEMENTATION ISSUES

There were few notable implementation issues during this project. No large issues were identified with the UX-Analyze software package, and project objectives were achieved for the most part. The most notable performance objective failure was the relatively large percentage of "can't analyze" targets identified in the data set. During the project, all targets with poor β1 curves were classified as "can't analyze," resulting in a "can't analyze" list that included approximately 7 percent of the targets investigated. It is likely that a large number of the "can't analyze" targets were collected at EM61 target locations that may have been generated as targets due to EM61 noise or duplicate pick on an anomaly better represented by a different EM61 target. In cases such as these, an analysis of the signal amplitude and EM61 target vs. MetalMapper collection vs. MetalMapper fit locations may have resulted in fewer "can't analyze" targets.

REFERENCES

Environmental Security Technology Certification Program. 2011. *ESTCP Munitions Response Live Site Demonstrations: Pole Mountain Target and Maneuver Area, WY*. Draft 2, 1 June.

Parsons. 2011. *MetalMapper Data Analyses, Pole Mountain Target and Maneuver Area, ESTCP Project No. MM201157*. Draft 1, June.

APPENDIX A

POINTS OF CONTACT

Appendix A: Points of Contact

POINT OF CONTACT	ORGANIZATION	Phone Fax e-mail	Role in Project
Dr. Jeff Marqusee	ESTCP Program Office 901 North Stuart Street, Suite 303 Arlington, VA 22203	703-696-2120 (V) 703-696-2114 (F) jeffrey.marqusee@osd.mil	Director, ESTCP
Dr. Anne Andrews	ESTCP Program Office 901 North Stuart Street, Suite 303 Arlington, VA 22203	703-696-3826 (V) 703-696-2114 (F) anne.andrews@osd.mil	Deputy Director, ESTCP
Dr. Herb Nelson	ESTCP Program Office 901 North Stuart Street, Suite 303 Arlington, VA 22203	703-696-8726 (V) 703-696-2114 (F) 202-215-4844 (C) herbert.nelson@osd.mil	Program Manager, MR
Ms. Katherine Kaye	HydroGeoLogic, Inc. 11107 Sunset Hills Road, Suite 400 Reston, VA 20190	410-884-4447 (V) kkaye@hgl.com	Special Projects Consultant, MR
Mr. Daniel Ruedy	HydroGeoLogic, Inc. 11107 Sunset Hills Road, Suite 400 Reston, VA 20190	703-736-4531 druedy@hgl.com	Program Assistant, MR
Dr. Shelley Cazares	Institute for Defense Analyses 4850 Mark Center Drive Alexandria, VA 22311	703-845-6792 (V) 703-578-2877 (F) scazares@ida.org	Performance Assessment
Ms. Jane Francis	Wyoming Dept. of Environmental Quality 122 West 25th Street Herschler Bldg., 4-W Cheyenne, WY 82002	307-777-7092 (V) jfranc@wyo.gov	State Regulator
Ms. Adrienne Nunn	Wyoming Dept. of Environmental Quality 122 West 25th Street Herschler Bldg., 4-W Cheyenne, WY 82002	307-777-6428 (V) anunn@wyo.gov	State Regulator

Mr. Larry Sandoval	Medicine Bow-Routt NF	307-745-2337 (V) lwsandoval@fs.fed.us	Laramie District Ranger
Mr. Nate Haynes	Medicine Bow NF Laramie Ranger District 2468 Jackson St., Laramie, WY 82070	307-745-2317 nhaynes@fs.fed.us	On Site Contact
Ms. Laura Percifield	Project Manager Environmental Remediation Branch USACE - Omaha District	402-995-2761 (V) laura.j.percifield@usace.army.mil	USACE Representative
Dr. Stephen Billings	Sky Research, Inc. 445 Dead Indian Memorial Road Ashland, OR 97520	541-552-5185 (V) 541-488-4606 (F) steve.billings@skyresearch.com	Lead PI
Mr. Heesoo Chung	Sky Research, Inc.	303-868-9309 Heesoo.Chung@skyresearch.com	Lead Data Collector
Ms. Victoria A. Kantsios	URS Group, Inc. 2450 Crystal Drive Suite 500 Arlington, VA 22202	703-418-3030 (V) 703-418-3040 (F) victoria_kantsios@urscorp.com	Lead PI
Mr. Darrell Hall	URS Group, Inc.	402-334-8181 darrell_hall@urscorp.com	Project Geophysicist
Dr. Dean Keiswetter	SAIC 120 Quade Drive Cary, NC 27513	919-677-1560 (V) 919-678-1508 (F) keiswetterd@saic.com	Lead PI
Mr. Levi Kennedy	Signal Innovations Group, Inc. 1009 Slater Rd., Ste. 200 Durham, NC 27703	919-323-3456 (V) 919-287-2398 (F) lkennedy@siginnovations.com	Lead PI
Dr. Len Pasion	Sky Research, Inc. Suite 112A, 2386 East Mall Vancouver, BC V6T 1Z3	541-552-5185 (V) 541-488-4606 (F) len.pasion@skyresearch.com	Lead PI

Mr. Greg Van	Parsons 1700 Broadway, Suite 900 Denver, CO 80290	303-764-1927 (V) 303-831-8208 (F) Greg.Van@Parsons.com	Lead PI
Mr. John Baptiste	Parsons 1700 Broadway, Suite 900 Denver, CO 80290	303-764-8840 John.E.Baptiste@parsons.com	Data Analyst
Ms. Elise Goggin	USACE, Huntsville	256-895-1635 Elise.M.Goggin@usace.army.mil	Data Analyst
Mr. Rick Grabowski	USACE, Omaha District	402-995-2284 richard.j.grabowski@usace.army.mil	Data Analyst
Mr. Tim Deignan	Shaw Environmental, Inc.	720-554-8273 timothy.deignan@shawgrp.com	Data Analyst